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The features of EUV light generation from Sn discharge produced plasma source with rotating disk electrodes

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ABSTRACT

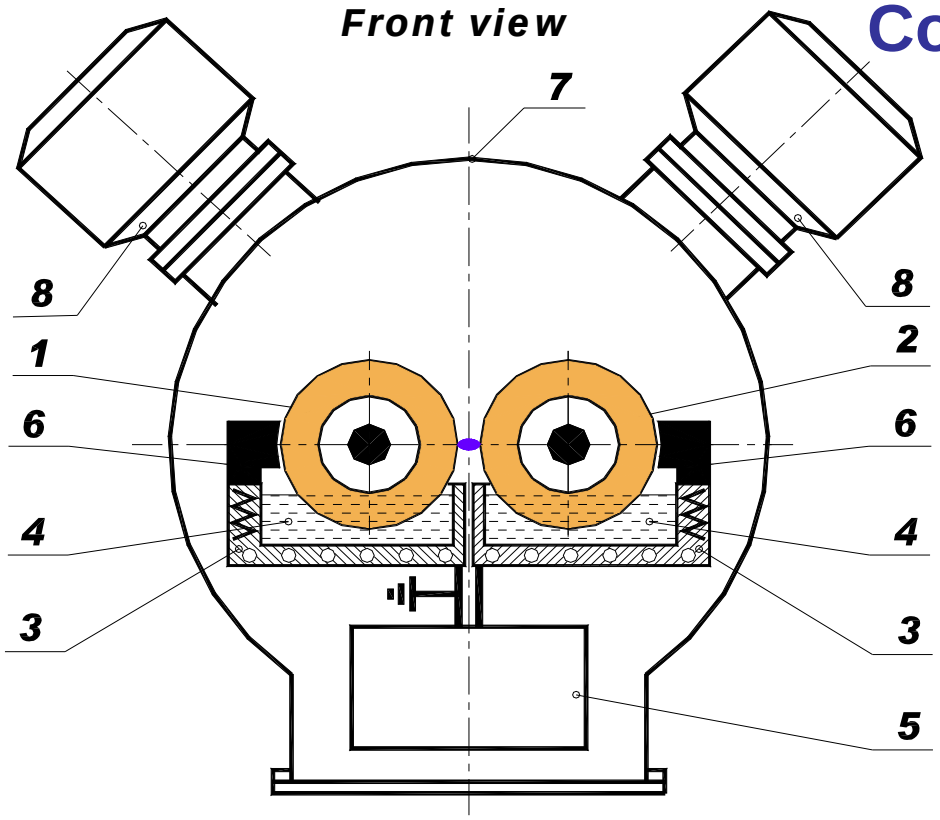
In this paper we show some characteristics of new Sn DPP source which has been designed to achieve the kilowatt level of the EUV power in 2π sr. The pulse power system of the source includes two steps of pulse compressing , prepulse circuit and recuperation circuit.

We have shown that KrF laser beam focusing on the anode makes it possible to obtain small EUV emitting plasma volume (~1mm3) at input energy up to 12 J per pulse using prepulse. The source had been operating at 2 kHz with EUV power level 520 W in 2π sr in 10 seconds burst.

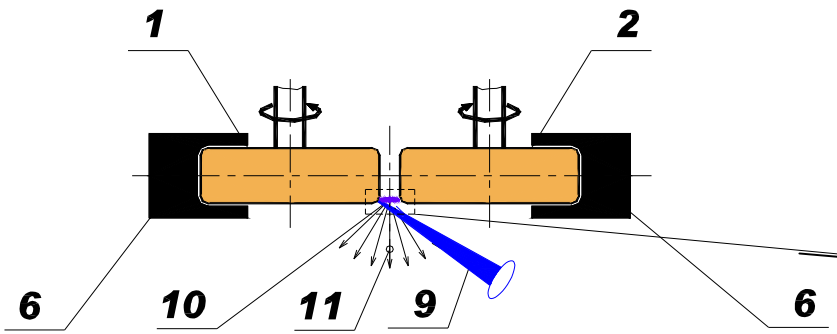
The separate experiments have shown that EUV generation depends on both thickness of tin layer and laser parameters (wavelength and intensity). 580 W in 2π sr had been obtained with Nd:YAG laser at 3.8 kHz

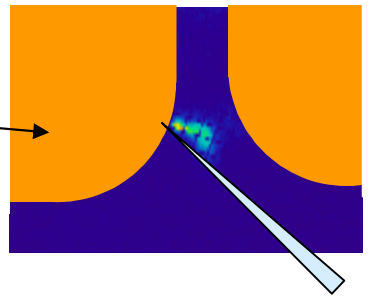
Based on our experimental result we show that EUV power level matched the HVM requirements can be achieved at the moderate (≤20kHz) repetition frequency

Conceptual diagram of the source with rotating disk electrodes



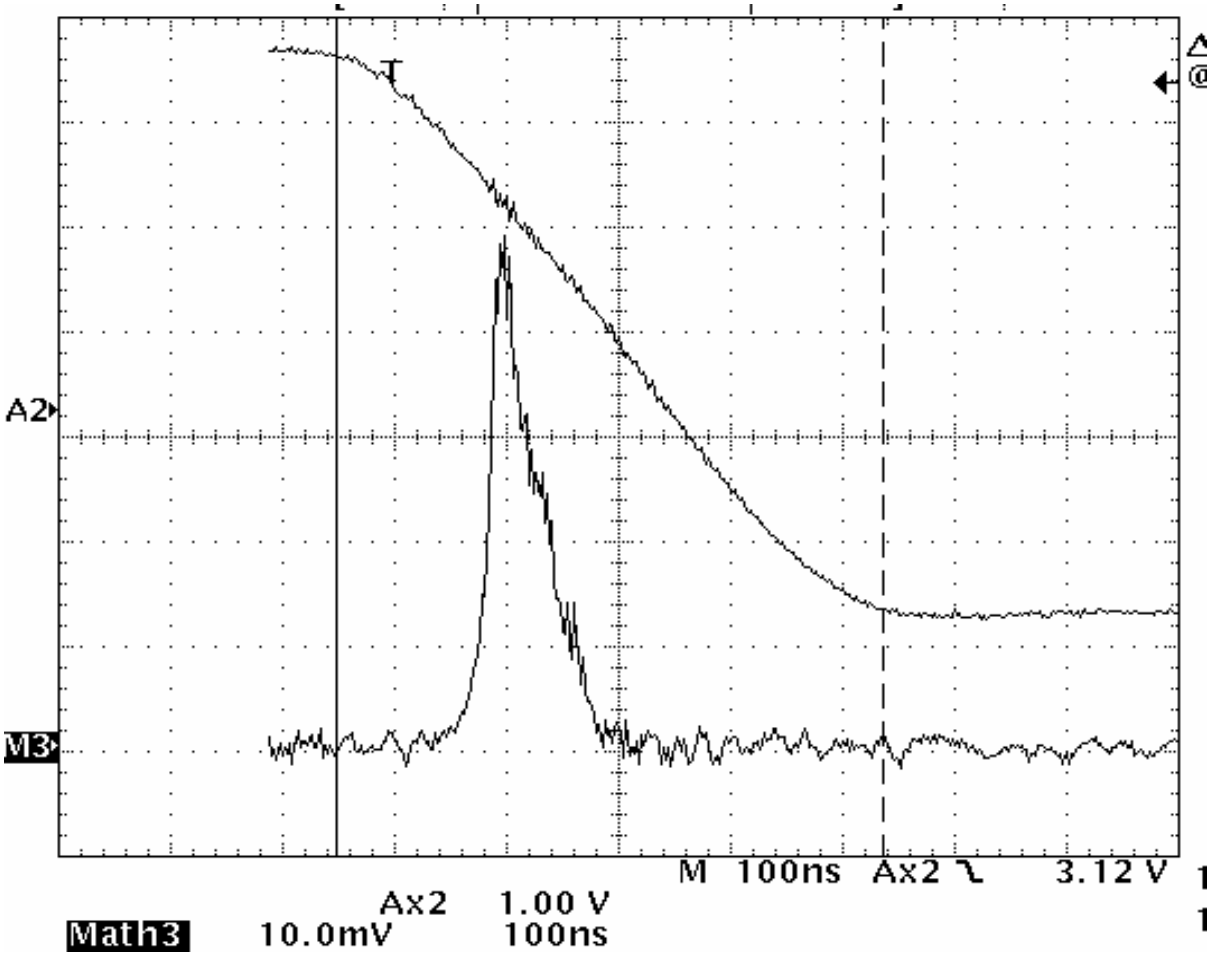
1- rotating electrode on which focus laser beam;
2 - second rotating electrode;
3 - body of bathes;
4 - liquid tin;
5 - pulse power system;
6 - regulation of tin layer;
7 - vacuum chamber;
8 - turbo-vacuum pump;
9 - laser beam position;
10 - discharge plasma;
11 - EUV radiation





New DPP source with rotating disk electrodes

The pinch occurs near the electrode on which laser beam is focused



Oscillograms of the voltage and the EUV pulse at the input energy 8.5 J

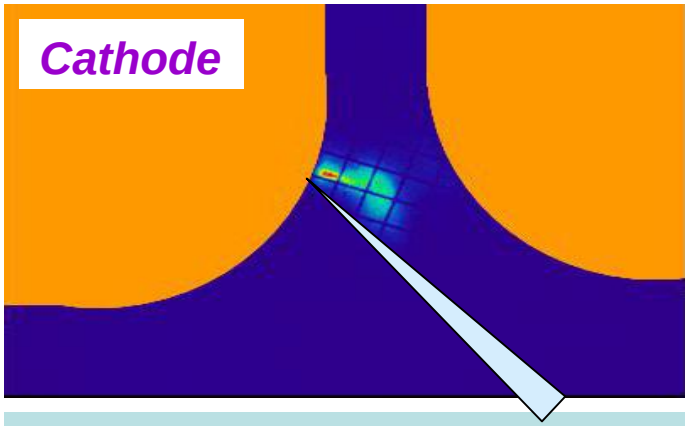


Image of the plasma. Laser beam was focused on the cathod. Ein=8.5 J, Zr filter

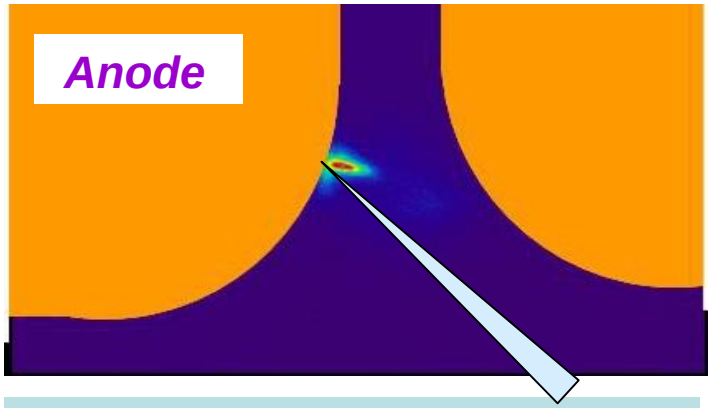
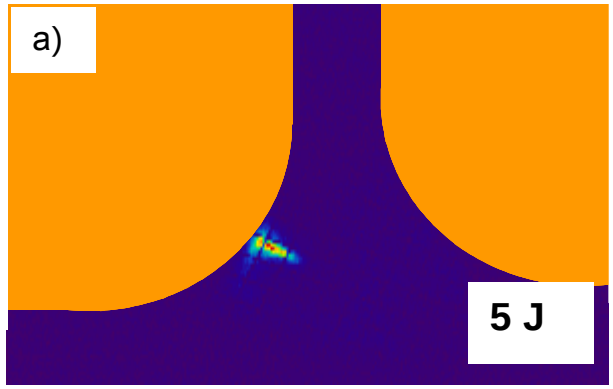
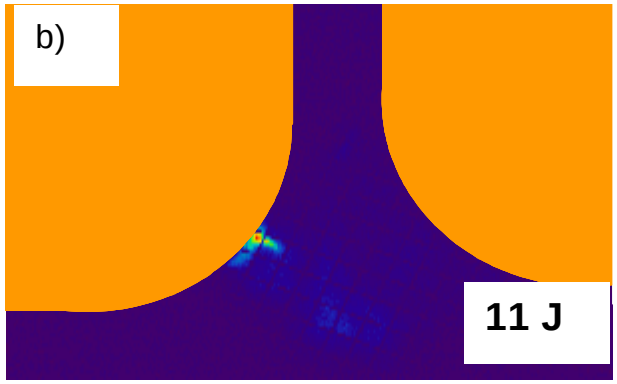


Image of the plasma. Laser beam was focused on the anod. Ein=8.5 J, Be filter

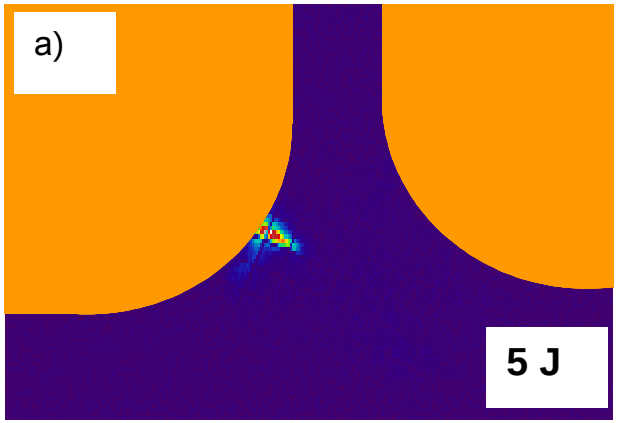
Improving the collection efficiency K through the addition a prepulse circuit

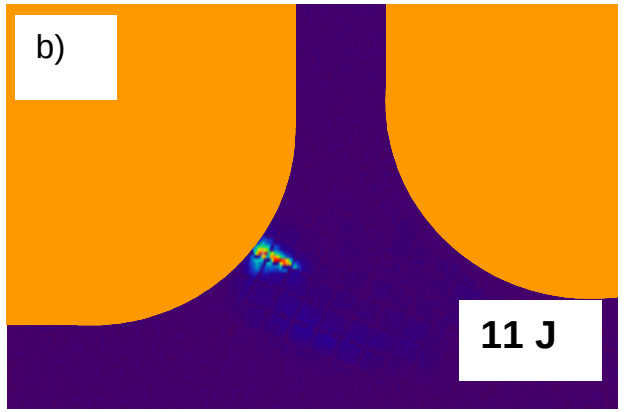




Images of the plasma at different input energy without using pre-pulse

a) E_{in}=5J , K=77%, ***b) E_{in} =11J, K=53 %***

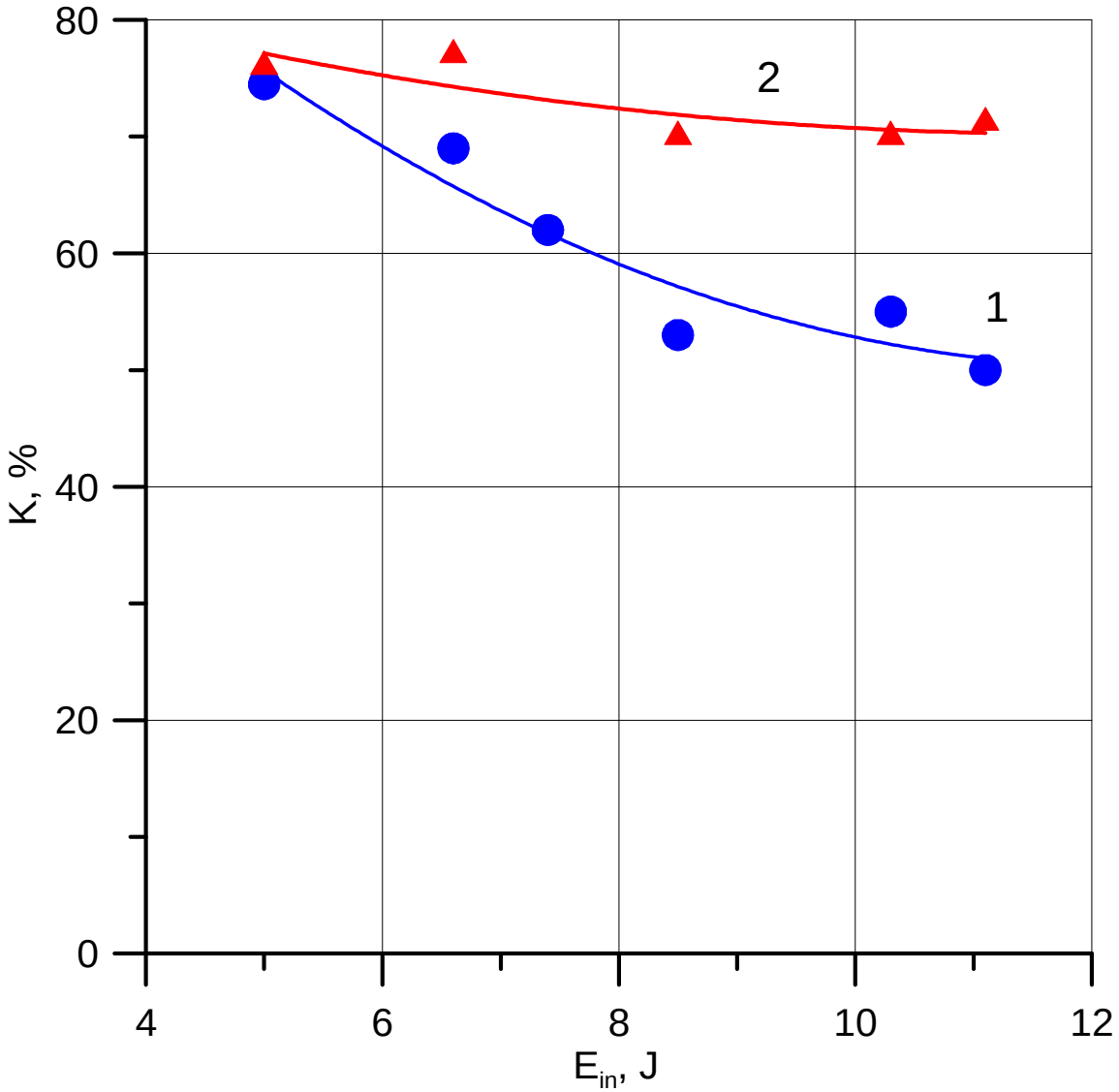




Images of the plasma at different input energy with using pre-pulse

a)- E_{in}=5J , K=76%, ***b) - E_{in}=11J, K=70% !***

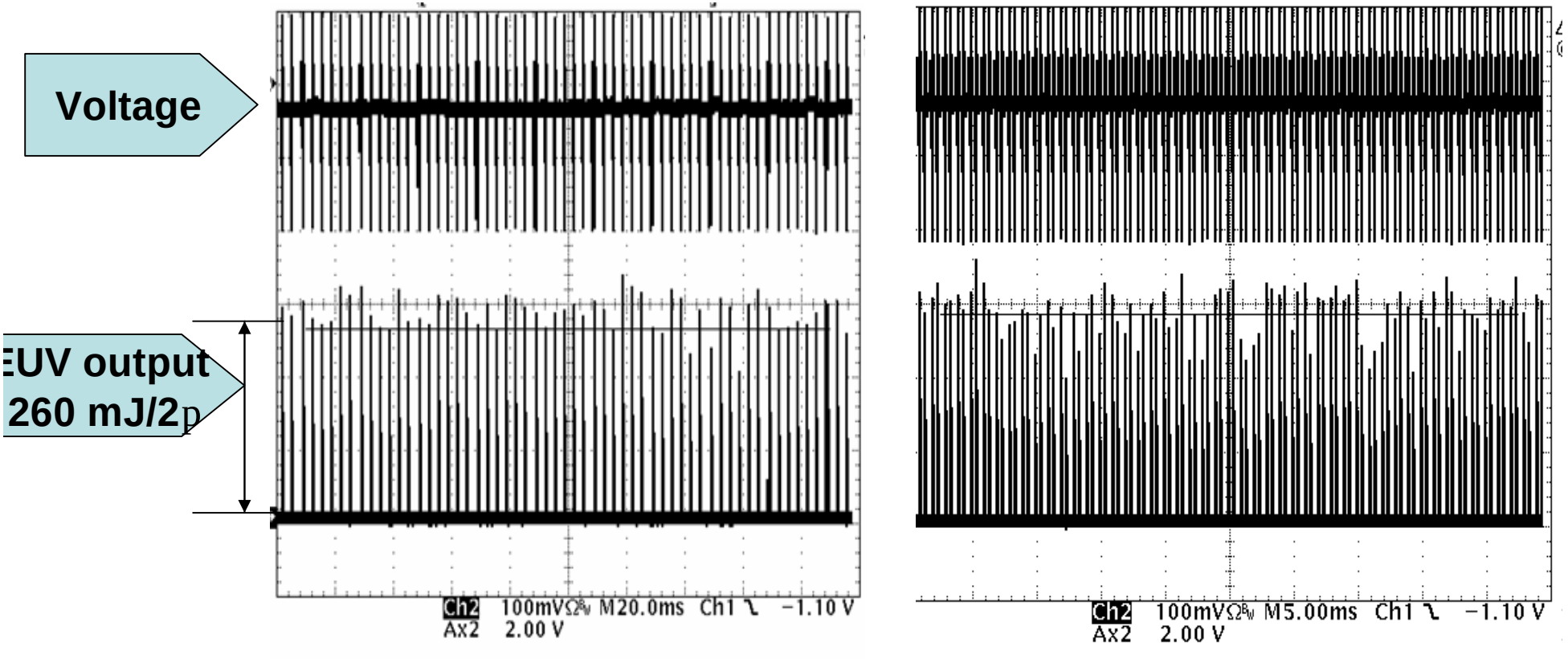
The position of the rotating electrodes given on the figures for obviousness



Using pre-pulse as small current through discharge gap before high current breakdown makes possible to increase collection efficiency K up to 70% at high input energy (6-11 J)

Dependences of collection efficiency on input energy in excitation circuit without (1) and with pre-pulse (2).

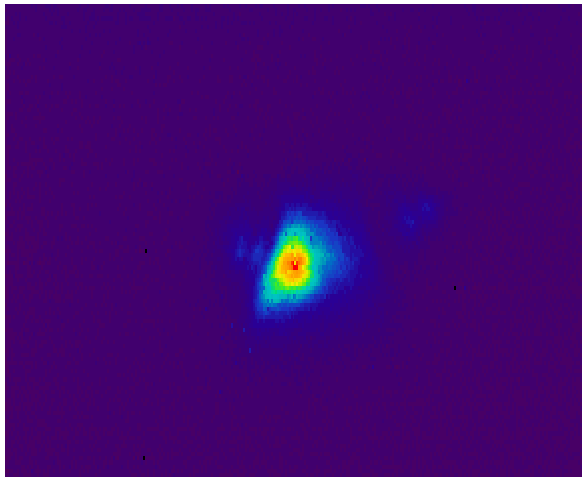
520 W in band in 2p sr at 2 kHz is obtained with pulse power system without recuperation



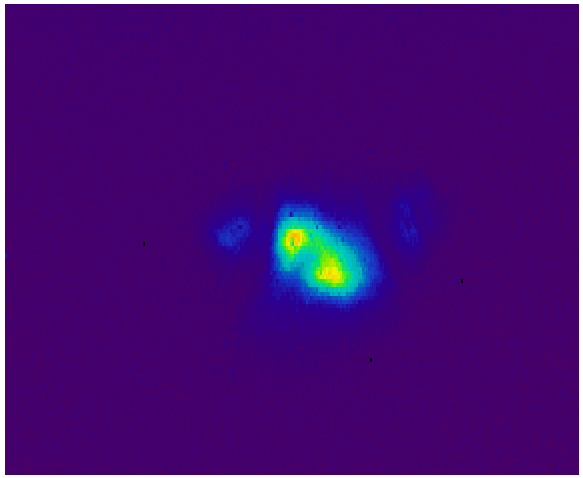
300 Hz

2000 Hz

EUV images of the plasma (E_{in}=9J, f=2kHz) at different KrF laser energy (E_{las})



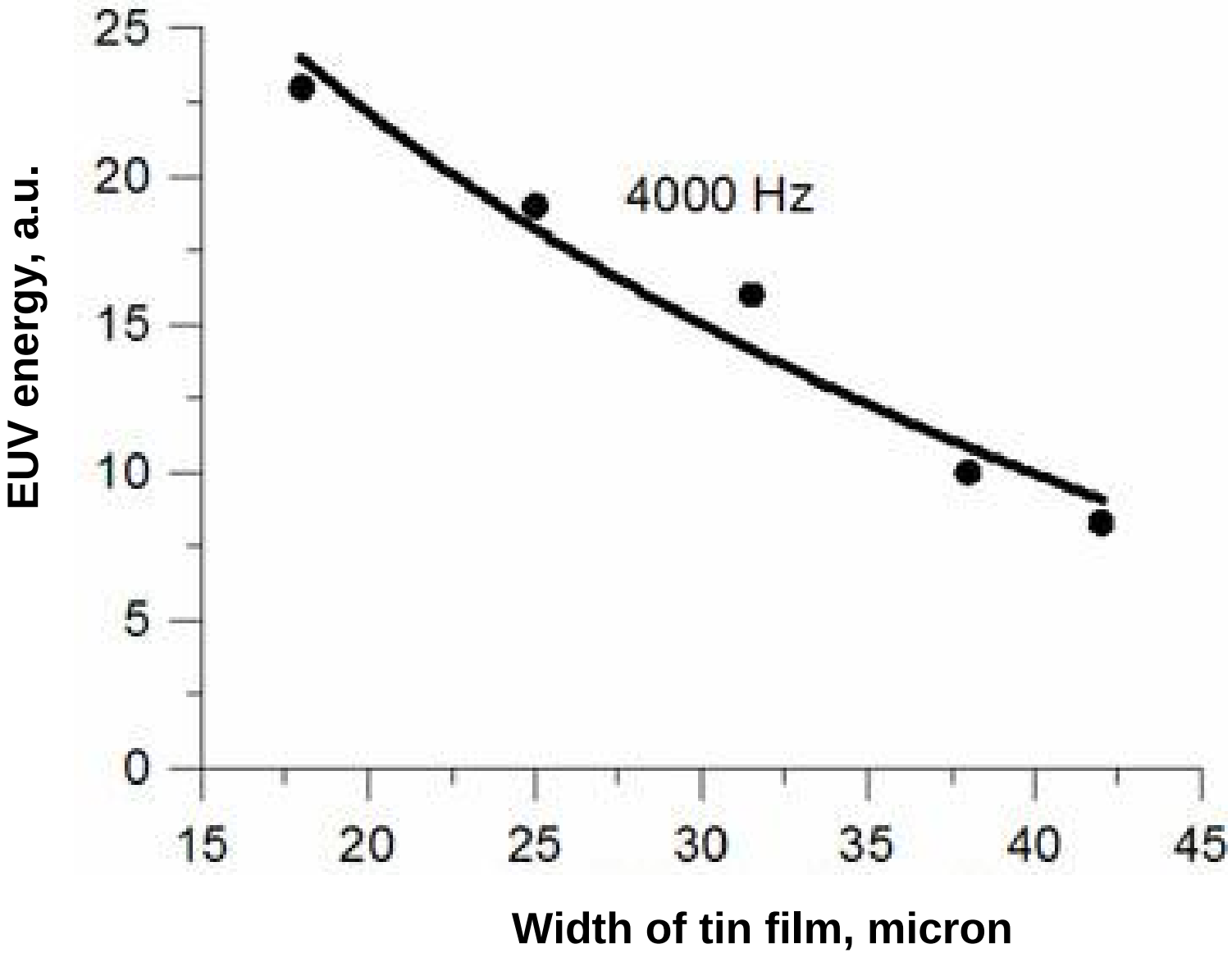
E_{las}=20 mJ



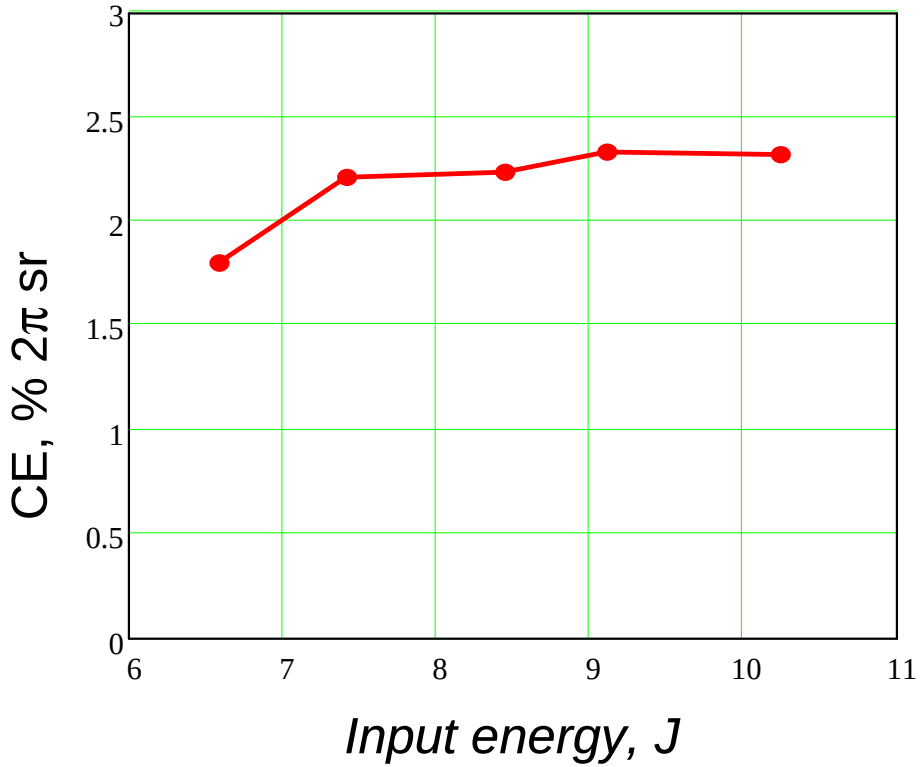
E_{las}=13 mJ

In the case of laser energy achieving the anode is high (Elas ≥ 20 mJ) alone bright pinch near the anode is formed. If laser energy is not sufficiently high (Elas < 20 mJ) bright EUV light near the cathod is clearly defined.

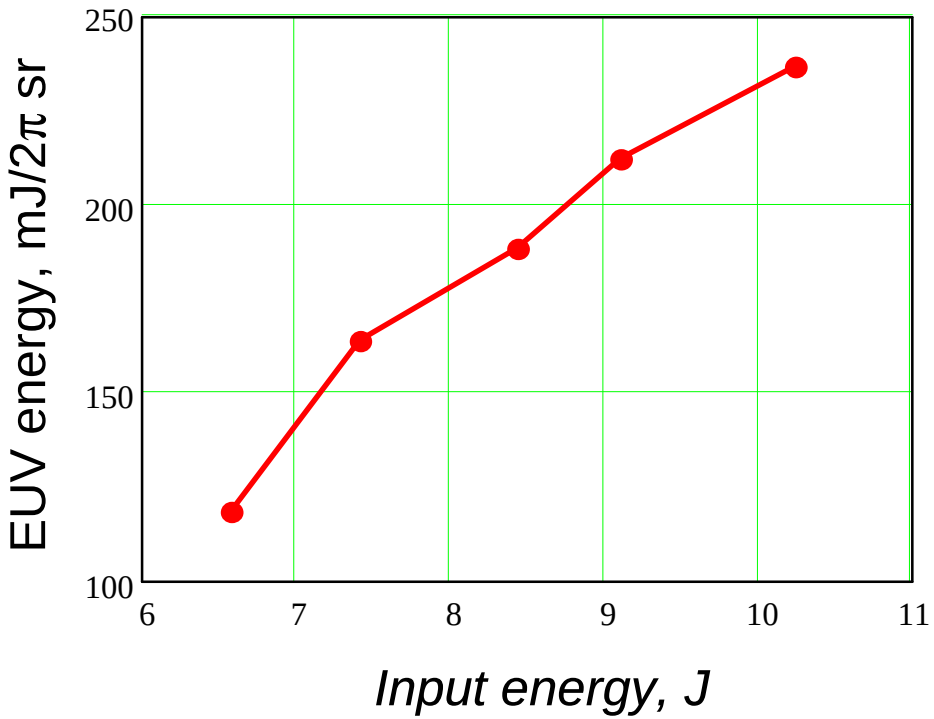
Dependence EUV energy on tin film width



Using pulse power system with a recuperation

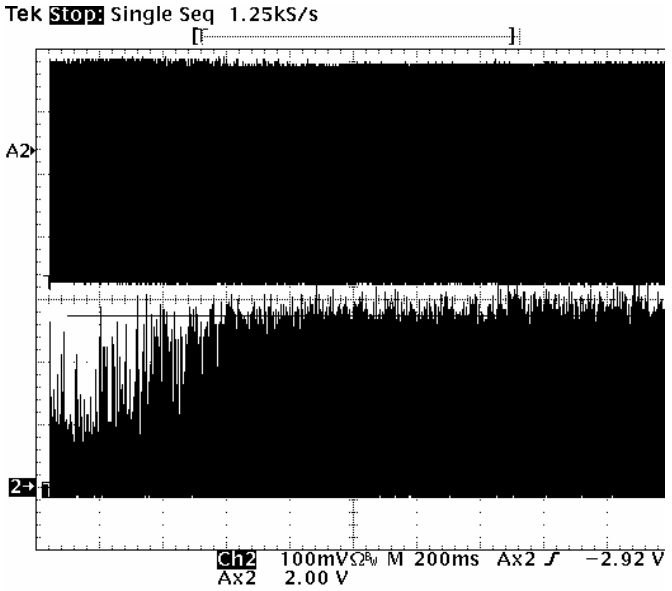


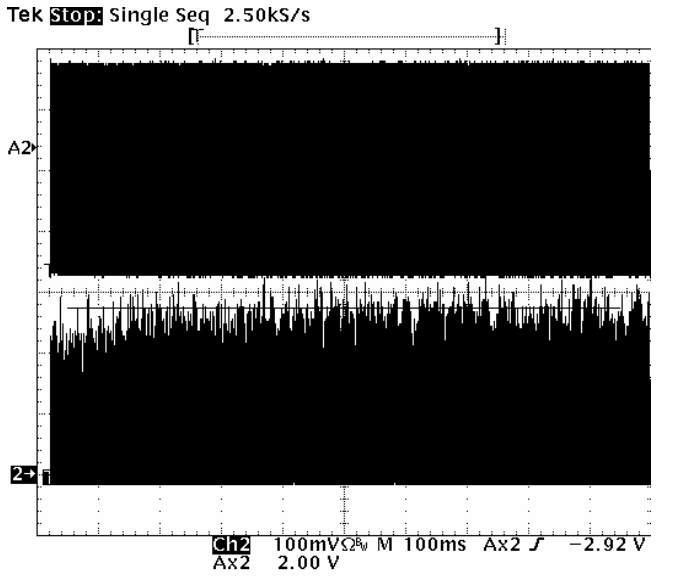
Dependence of conversion efficiency on the input energy

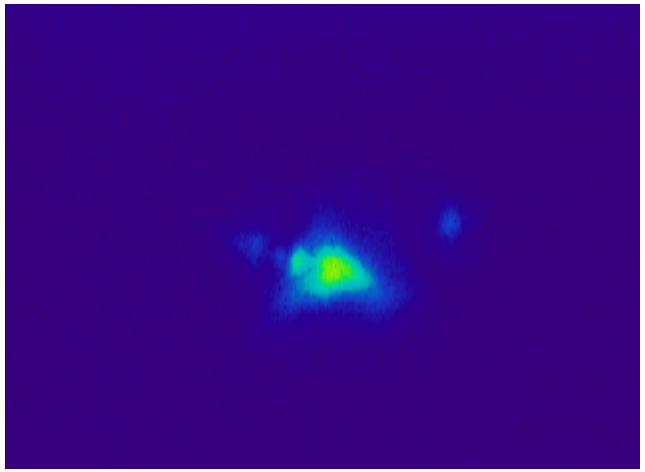


Dependence of EUV energy on the input energy

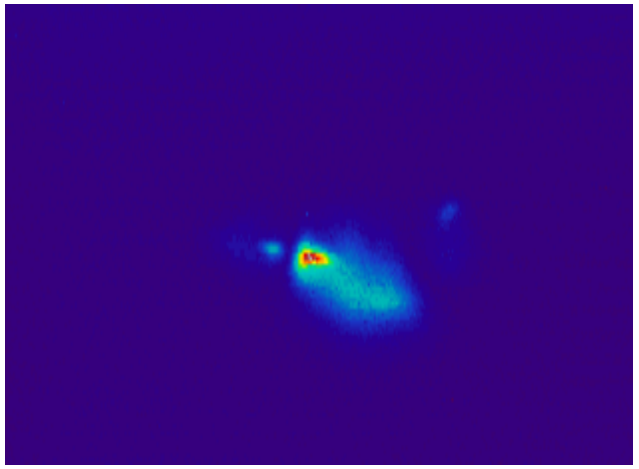
Source operation at different disk rotation speed







ω=1 rot/sec



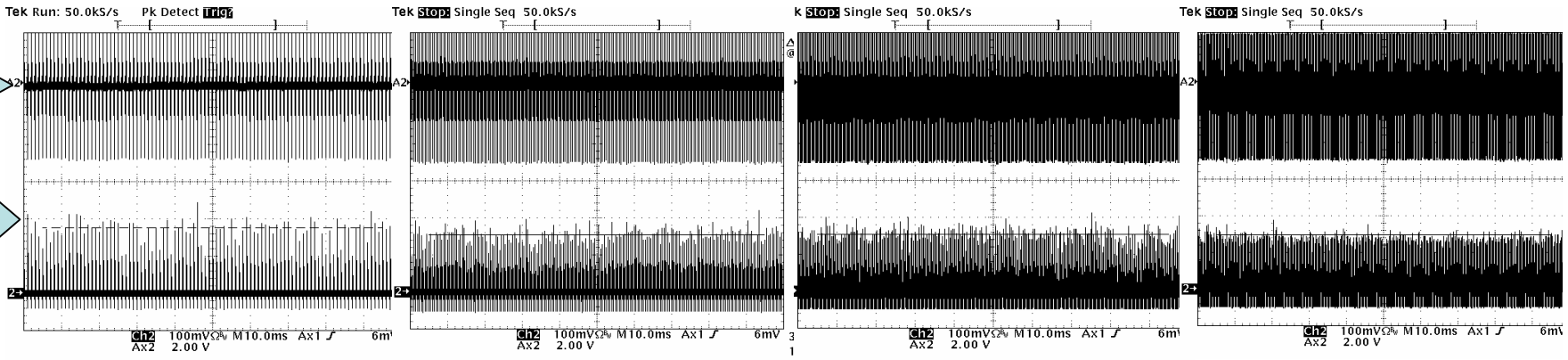
ω=4 rot/sec

In the case of disk rotation speed is not sufficiently high (ω=1 rot/sec) EUV signals do not change but the bright pinch is absent

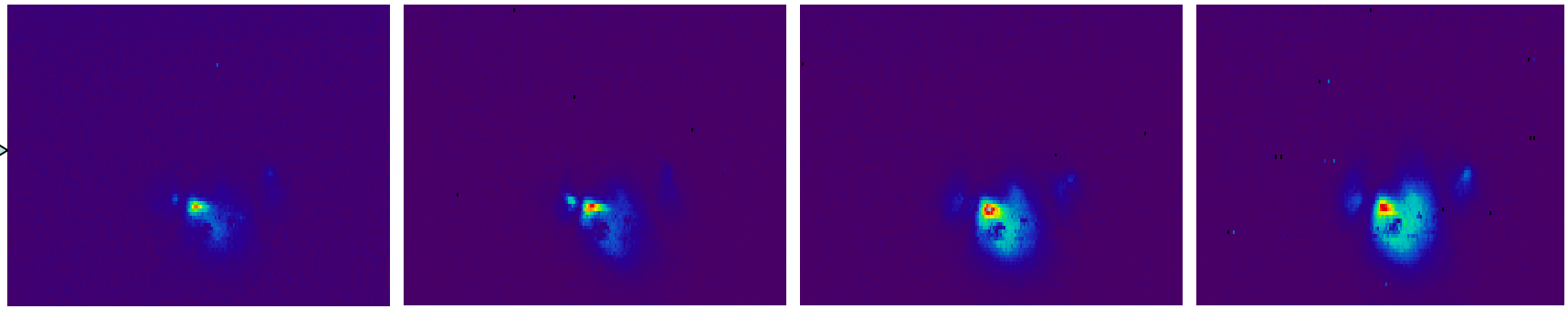
Operation of Sn DPP source with pulse power system including recuperation and Nd:YAG laser

Voltage

EUV output 153 mJ/2p



EUV image



1 kHz | 2 kHz | 3 kHz | 3.8 kHz

EUV power 153 mJ x 3.8 kHz ≈ 580 W /2π

Conclusion

New Sn DPP source designed to achieve multi kilowatt level of EUV power started to work. 520 W EUV power in band in 2π at 2 kHz without recuperation and 580 W with recuperation at 3.8 kHz were obtained.

Next steps: scalability of Sn DPP source to HVM levels by increase a pulse repetition frequency up to 20 kHz using more powerful both Nd:YAG laser and pulse power system.

Acknowledgements

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